Decomposition and Nutrient Release Patterns of *Pueraria phaseoloides* and *Flemingia macrophylla* Under Two Rainfall Regimes

B. Banful[1,2]✉*, S. Hauser*[1]*, F. Kumaga*[3]*, K. Ofori*[3]*, R. Ndango*[1]
[1]*Humid Forest Ecoregional Centre, International Institute of Tropical Agriculture (IITA), B.P. 2008, Messa, Yaounde, Cameroon;* [2]*Crops Research Institute, P. O. Box 3785, Kumasi, Ghana;* [3]*Crop Science Department, University of Ghana, Legon, Ghana.*
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Resumé
Banful, B., Hauser, S., Kumaga, F., Ofori, K. & Ndango, R. *Les Modèles de la Décomposition et le Transfert des Nutriments dans le Cas de Pueraria Phaseoloides et Flemingia Macrophylla sous deux Régimes Pluvieux.* Nous faisons notre réportage sur une étude pour déterminer les modèles de la décomposition et le transfert des nutriments dans le cas de Pueraria Phaseoloides et flemingia macrophylla sous deux régimes pluvieux au sud du Caméroon. Frais matériau de feuille des espèces légumineuses étaient mis dans des boîtes litières et placés sur la superficie du sol pour 120 jours à Ngoumou (pluie intenses) et Nkometou (pluies non intenses). La perte en masse des feuilles était plus rapide en P. phaseoloides que F. macrophylla tel que "démi vies" ont rangé entre 9.0 et 9.5 semaines dans le cas de P. phageoloides et 14.6 et 12.1 semaines dans le cas de F. macrophylla. Le pourcentage de feuille qui reste était plus grand à Nkometou avec un moyen "démi-vies" de 14.6 et 12.1 semaines respectivement. Le transfert des nutriments (N,P,K, Ca et Mg) était plus rapide et en grande qualité dans le cas de p. phaseoloides que F. macrophylla. Plus de la moitié des composants N dans P. phaseoloides étaient transférés en 9 semaines. Généralement, la moitié de K transféré de chaque espèce légumineuses était dans la première 5 semaines. Parmi les villages, le niveau de transfert de chaque composant nutrif était plus rapide à Ngoumou qu' à Nkometou. L'étude a conclu que pueraria phaseoloides possèdait un niveau plus élevé de transfert des nutriments et donc capable d'assurer la disponibilité des nutriments aux cultures associeées en grande quantité.

Mots clés: Pluviométrie, perte en masse, perte de nutriment, culture en jachère.

Abstract
We report on a study to determine the decomposition and nutrient release patterns of *Pueraria phaseoloides* and *Flemingia macrophylla* leaf residues under two rainfall regimes in southern Cameroon. Fresh leaf material of the two legume species were put in litter bags and placed on the soil surface for 120 days at Ngoumou (high rainfall) and Nkometou (low rainfall). Mass loss of the leaf residue was faster in *P. phaseoloides* than *F. macrophylla* such that half-lives ranged from 9.0 - 9.5 weeks for *P. phaseoloides* and 14.6 - 20.2 weeks for *F. macrophylla*. Per cent leaf mass remaining was greater ($p < 0.05$) at Ngoumou than at Nkometou with mean half-lives being 14.6 and 12.1 weeks, respectively. The release of

✉ *Corresponding author*

nutrients (N, P, K, Ca and Mg) was faster and in greater quantities in *P. phaseoloides* than *F. macrophylla.* More than half of the constituent N in *P. phaseoloides* was released in 9 weeks. Generally, half of K released from either legume species was within the first 5 weeks. The rate of release of each constituent nutrient was faster at Ngoumou than at Nkometou. The study concluded that *P. phaseoloides* had the largest amounts and rates of nutrient releases and therefore could ensure greater nutrient availability to associated crops.

Keywords: Rainfall, mass loss, nutrient loss, planted fallows.

Introduction

In the humid tropics of West and Central Africa, the sustainability of "slash and burn", the traditional farming system, relies on long fallow periods in-between the cropping phases (Henrot and Brussaard, 1997). As human population increases and land availability decreases, the fallows, traditionally used as weed-breaks (de Rouw, 1995) and for soil fertility regeneration are shortened. Widely used alternatives to slash and burn involve the use of organic mulches i.e tree or shrub pruning or leguminous cover crops for improved fallows. The decomposition and nutrient release of the organic mulches are key processes by which nutrients locked up in the plant residue eventually become available to crops. But for an effective nutrient conservation in the cropping system, the release of nutrients should be synchronized with the crop growth demand (Myers *et al.,* 1996). To achieve this synchrony, knowledge of the decomposition rates of the organic mulches is essential to characterise the mulch type and determine time of application. The processes of decomposition and nutrient release are regulated by a host of factors including physical and chemical properties of the residue, climate, soil properties and decomposer communities consisting of microorganisms and soil macrofauna (Meentemeyer and Berg, 1986; Upadhyay and Singh, 1989). Understanding the extent of influence of these factors over residue decay and nutrient release is an important step to better managing organic inputs that are incorporated into low-input crop management systems (Palm, 1995; Mafongoya *et al.*, 1997). Studies on residue decomposition of cover crops, (e.g. McDonagh *et al.*, 1995; Luna-Orea *et al.*, 1996) and hedgerow pruning (e.g. Handayanto *et al.*, 1997) are widely cited yet these studies dealt mostly with forest residue decay and were localized on single sites (Mugendi and Nair, 1997). Information on residue decomposition and nutrient release in bush fallow lands are unavailable despite the fact that human population pressure on land has confined most smallholder farmers to these degraded lands. There is also a dearth of knowledge on the role of differing environments on residue decomposition and nutrient release. This study was designed to determine in a bush land use system the decomposition and nutrient release characteristics of *P. phaseoloides* and *F. macrophylla* leaf residues under two rainfall environments. These two plant species are in use in planted fallow systems in West and Central Africa.

Materials and methods

Description of experimental locations

The study was carried out in two villages in southern Cameroon; Nkometou (4° 05'N, 11° 33'E) and Ngoumou (3° 41'N, 11° 25'E), representing two rainfall regimes (Figure 1). Mean annual precipitation is 1218 mm at Nkometou and 1720 mm at Ngoumou. The soils at Ngoumou and Nkometou are both classified as clayey, kaolinitic, Typic Kandiudult (Hulugalle and Ndi, 1993). The sites have a bimodal rainfall distribution, with peaks in June and September. The major dry season starts in mid November and lasts through end of February or beginning of March. In each village, the experiment was laid out in a 4-5 year-old bush natural fallow.

Experimental procedure

Fields were slashed in January and burned in mid to late February 2002. In each village, the experiment was laid out in a randomized complete block with three replications. The treatments comprised two leguminous species planted as *F. macrophylla* hedgerows and *P. phaseoloides* cover crop. Each plot measured 15 m x 12 m. Planting was done in early June 2002 at Nkometou, and late June at Ngoumou. The *F. macrophylla* hedgerows were planted by drilling seeds at 4 kg ha^{-1} in rows of 12 m length and 3 m apart. *Pueraria phaseoloides* was established from seed by drilling at 12 kg ha^{-1} in four double rows spaced 1 m between two rows and 2 m between adjacent double rows.

Soil chemical analyses

In April 2004, nine soil cores of 0-10 cm depth were collected per plot. One composite of the nine samples was made to obtain one sample per plot. Soil samples were air-dried and ground, mixed thoroughly and sub-sampled for chemical analyses. The following procedures were adopted for the analyses. pH was determined in 1:2.5 (w/v) soil: water suspension. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) and phosphorus were extracted by the Mehlich-3 procedure (Mehlich, 1984). Cations were determined by atomic absorption spectrophotometry and phosphorus by the molybdate blue procedure described by Murphy and Riley (1962). Organic carbon was determined using Heanes digestion and spectrophotometric procedure (Heanes, 1984). Total nitrogen was determined on a wet acid digest (Buondonno *et. al.*, 1995) and read colorimetrically (Anderson and Ingram, 1993).

Soil texture analysis

Soil samples were initially collected from each undisturbed plot before laying out the field for planting. Thirty six core samples were collected per plot using a 100 cm^3 cylindrical soil core at

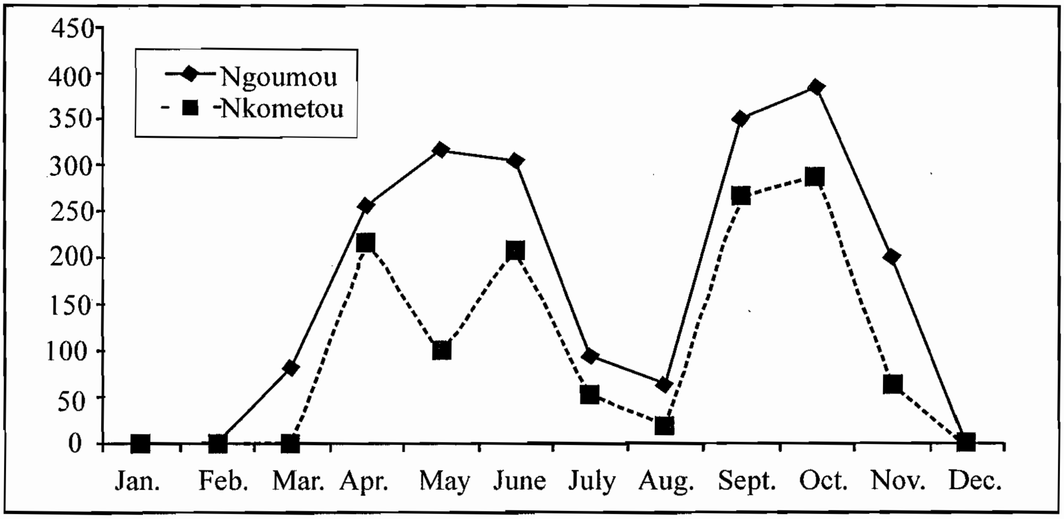

Figure 1. Rainfall pattern at Ngoumou and Nkometou in 2004.

depth of 0-10 cm. Soil texture was determined according to Day (1965).

Determination of chemical characteristics of the leaf materials

The leaves of *P. phaseoloides* and *F. macrophylla* were harvested fresh, 20 months after planting of the legume species, and air-dried. Sub-samples were ground and passed through 0.5 mm sieve and analysed for total N, P, K, Ca, and Mg. Total N was determined on a wet acid digest (Buondonno *et al.*, 1995) and read colorimetrically (Anderson and Ingram, 1993). Calcium, Mg and K were determined by atomic absorption spectrophotometry (Jones and Case, 1990) while total P was determined using the procedure of Murphy and Riley (1962).

Decomposition experiment

Decomposition and nutrient release from the leaf materials were determined in the field using the litterbag technique. The experiment was conducted from April to July, 2004 in the plots of the established *F. macrophylla* and *P. phaseoloides* at the two villages. Litterbags (30 x 30 cm) were constructed from aluminium net with 2 mm mesh size. The plots were distributed in a randomised complete block design with three replications and two leaf residue treatments; *F. macrophylla* and *P. phaseoloides*. Litterbags were filled with 100 g of fresh leaves and sealed. The litterbags were placed flat at random on the surface of the soil in 5 x 4 m plots. Five litterbags of each residue treatment were placed in plots corresponding to the respective leguminous species. A field map was drawn to identify the residues in each plot. Vegetation at each site was controlled by hand weeding. One litterbag was collected from each plot at 20, 60, and 120 days after placement to monitor dry matter and nutrient loss. The leaf material remaining in the litterbags at each time were separated from soil and organic debris by hand and oven dried at 65 °C to constant mass. Sub-samples were then ground and passed through 0.5 mm sieve and analysed for total N, P, K, Ca, and Mg contents. The amount of nutrients remaining in the litterbag at each sampling time was determined by multiplying the masses of residue remaining by their respective concentrations. It was assumed that the amount of nutrients released or immobilized at each time was the difference between the amount of nutrients contained in the initial leaf materials and the amounts in the materials at the given sampling time.

The decomposition and nutrient loss constants, k, were determined by the negative single exponential model,

$$m = m_0 e^{-kt} \quad \ldots \quad \ldots \quad (1)$$

where m is the mass of material or nutrient remaining at each time, t, in days and m_0 is the initial mass of material or nutrient (Wieder and Lang, 1982). Half-life (t_{50}), the time when 50% of the material would have decomposed (or half of the nutrients would have been released) was calculated as:

$$t_{50} = \frac{0.692}{k} \quad \ldots \quad \ldots \quad (2)$$

Statistical analysis

Data were analysed using the general linear model (GLM) procedure of SAS (SAS, 1997). The Least Significant Differences (LSD) were computed and used to separate the treatment means at $p < 0.05$.

Results

Soil physico-chemical characteristics

Soils at Ngoumou and Nkometou were both classified as sandy clay loam and therefore not different in texture ($p <$ 0.05). Soil nutrient contents were also not different between the two villages (Table 1), but soil at Ngoumou was more acidic than at Nkometou.

Quality characteristics of the leaf residues

There were no residue x village interactions in leaf nutrient contents, and as such the data were pooled across villages. *Pueraria phaseoloides* contained more N, K, Ca and Mg than *F. macrophylla* (p <0.01), the difference being at least 30% (Table 2). However the N concentrations of the two leaf residues were greater than the critical level of 18 to 22 g kg^{-1} below which net N immobilization from soil would be expected (Palm *et al.,* 1997). The P concentrations of both leaf residues were similar and below the critical level of 2.5 g kg^{-1} (Janssen, 1993), thus immobilization of P would be expected. The C/N ratios were below 25, which may result in rapid release of mineral N during decomposition.

Table 1. Selected chemical properties of soils at 0-10 cm depth used in the study.

Parameter	Village Ngoumou	Village Nkometou
pH (H_2O)	4.4 b	5.3 a
Total N ($g\ kg^{-1}$)	1.69 a	1.77 a
Total C ($g\ kg^{-1}$)	28.09 a	29.39 a
Total P ($mg\ kg^{-1}$)	20,11 a	24.62 a
Ca ($cmol_c\ kg^{-1}$)	3.49 a	4.63 a
Mg ($cmol_c\ kg^{-1}$)	1.77 a	2.00 a
K ($cmol_c\ kg^{-1}$)	0.29 a	0.29 a

For each soil parameter, values followed by the same letter in a row are not different at p=0.05.
Data are means of three replicates.

Residue mass loss

There was residue x village interaction (p <0.05) in the percent leaf mass remaining such that the relative difference in leaf mass loss between *P. phaseoloides* and *F. macrophylla* changed from one village to another (Table 3.). Consequently, the half-lives of the leaf residues also varied from one village to another, and ranged from 14.6 weeks for *F. macrophylla*-Nkometou to 20.2 weeks for *F. macrophylla*-Ngoumou. Single exponential regression functions best fitted the data (Table 4). Residue mass loss was generally faster in *P. phaseoloides* than in *F. macrophylla*.

Nutrient release patterns

Nitrogen

Nitrogen release differed (p < 0.05) among leaf residues as well as in the villages at all retrieval periods. There were no residue x village interactions. Release of N was faster in *P. phaseoloides* leaf residues (Figure 2).

Table 2. Initial nutrient contents of leaf residues.

Leaf residues	*N*	*P*	*K*	*Ca*	*Mg*	*C*	*C/N*
	Nutrient concentration ($g\ kg^{-1}$)						
P. phaseoloides	40.88	2.12	11.88	10.02	3.38	455.41	11.17
F. macrophylla	31.25	1.99	8.87	6.82	1.90	473.90	15.18
t (prob.)	<0.001	ns	0.002	0.003	<0.001	<0.0001	<0.0001

Table 3. Per cent mass of the different leaf residues remaining during 120 days of decomposition at the two locations.

Leaf residue	*20 DAI*	*60 DAI*	*120 DAI* •
F. macrophylla	64.4	50.9	36.2
P. phaseoloides	51.3	32.5	17.9
P (residue)	0.0046**	0.0008***	0.0010**
Village			
Ngoumou	74.0	53.5	35.8
Nkometou	41.7	29.9	18.3
P (village)	<0.0001***	0.0002***	0.0012**
P (interaction)	0.001**	0.003**	0.037*

Probability (*p*) of differences between treatment means are * ($p < 0.05$), ** ($p < 0.01$) and *** ($p < 0.001$).
• *DAI* = days after incubation.

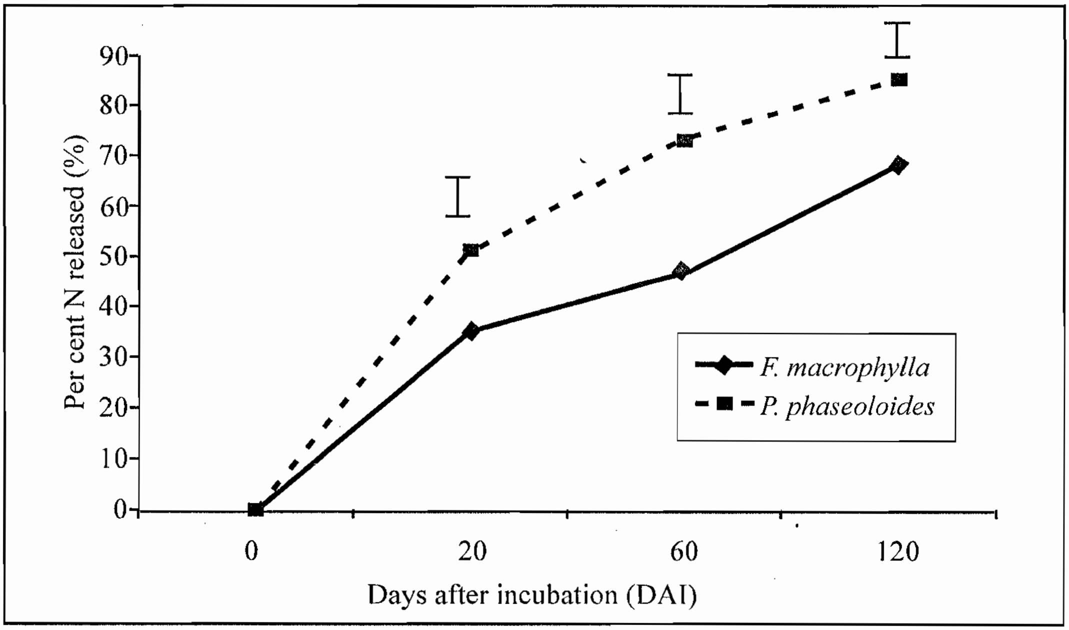

Figure 2. Nitrogen release patterns of leaf residues in Cameroon, 2004.

The faster N release (0.0105 day^{-1}) in *P. phaseoloides* resulted in a half-life of about 9 weeks. On the other hand, *F. macrophylla* released the least amount of N during the period of study. Release of N was slow (0.007 day^{-1}) with a half-life of 14 weeks (Table 5). At the end of the experimental period (17 weeks), *F. macrophylla* had more than 25% of its total N in the remaining leaf residue. Among the villages, Nkometou had overall greater N release than Ngoumou (Figure 3).

Table 4. Half-lives of leaf residues at Nkometou and Ngoumou, Cameroon in 2004.

Village	*Type of leaf material*	*Rate constant, k day^{-1}*	*r^2*	*Half-life (weeks)*
Nkometou	*F. macrophylla*	-0.0068	0.96 ***	14.6
	P. phaseoloides	-0.0104	0.96 ***	9.5
Ngoumou	*F. macrophylla*	-0.0049	0.99 ***	20.2
	P. phaseoloides	-0.0110	0.99 ***	9.0

***: Significant at $p < 0.001$.

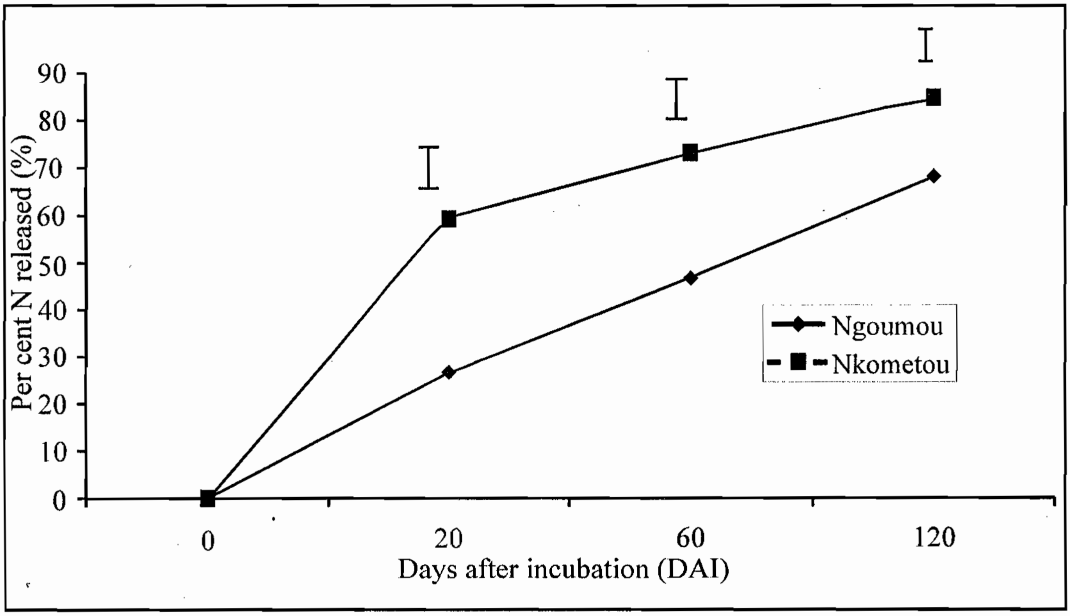

Figure 3. Nitrogen release patterns at Ngoumou and Nkometou, 2004.

Table 5. Half-life of nutrient release from the different leaf residues and at Ngoumou and Nkometou, Cameroon in 2004.

	Half-life (t_{50}, weeks).				
Leaf residues	*N*	*P*	*K*	*Ca*	*Mg*
P. phaseoloides	9.4	8.3	4.8	14.3	10.8
F. macrophylla	14.1	9.0	7.4	25.4	27.5
Villages					
Ngoumou	9.1	6.8	4.6	13.4	11.5
Nkometou	9.4	8.1	5.0	15.7	13.6

Phosphorus

The pattern of P release was similar for both species (Figure 4). There were no significant residue x village interactions. The half-lives of P releases were smaller than those of N releases (Table 5), an indication of faster rate of P releases. The pattern of P release between the villages was similar to that of N release.

Potassium

Proportions of K released from the leaf residues were greater than those for other nutrients (Figure 5). There were however no significant residue x village interactions. Potassium release was slowest in *F. macrophylla* (0.0134 day^{-1}), although the time required to release half of the K, in 7 weeks, was still less than for N and P releases (Table 5). The release of K followed a similar pattern as for N and P in both villages, though the release was faster compared to N and P. Except for *F. macrophylla*, half of K releases was within the first 5 weeks.

Calcium

The release of Calcium from the leaf residues was the slowest among all the nutrients. There were no significant residue x village interactions. The least amount of Ca was released by *F.*

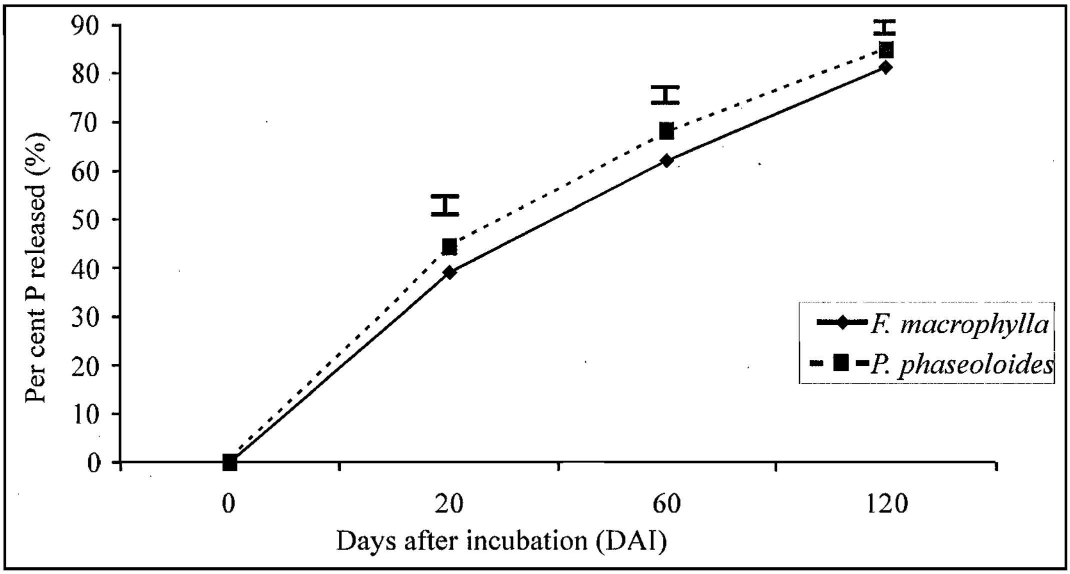

Figure 4. Phosphorus release patterns of leaf residues in Cameroon, 2004.

macrophylla (Figure 6). Similarly, releases of Ca at the villages were very slow with half of releases being made between 13.4 weeks (Ngoumou) and 15.7 weeks (Nkometou) (Table 5). Furthermore, Ca releases in the villages followed a pattern similar to the other nutrients.

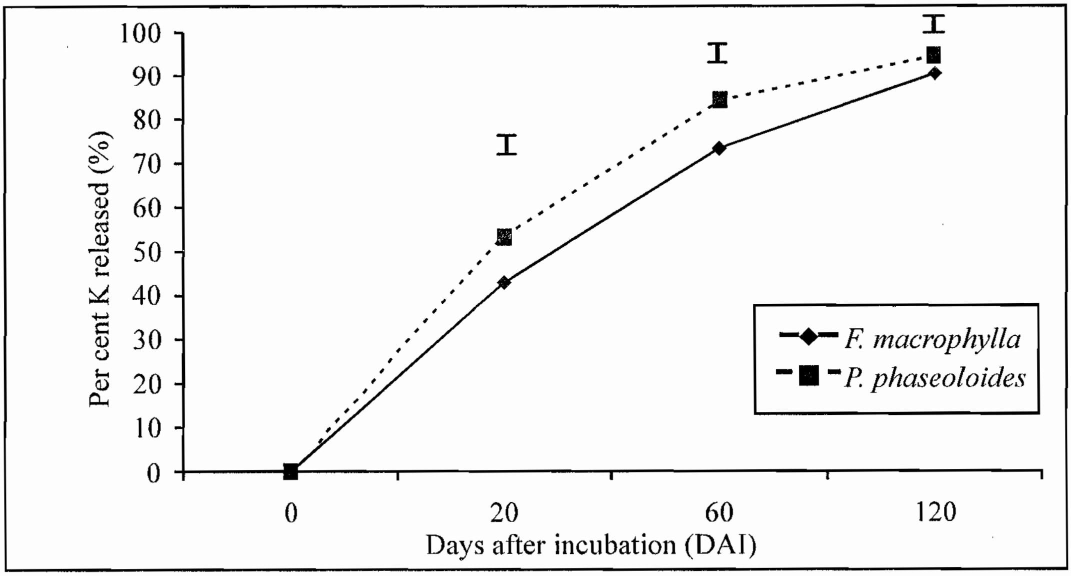

Figure 5. Potassium release patterns of leaf residues in Cameroon, 2004.

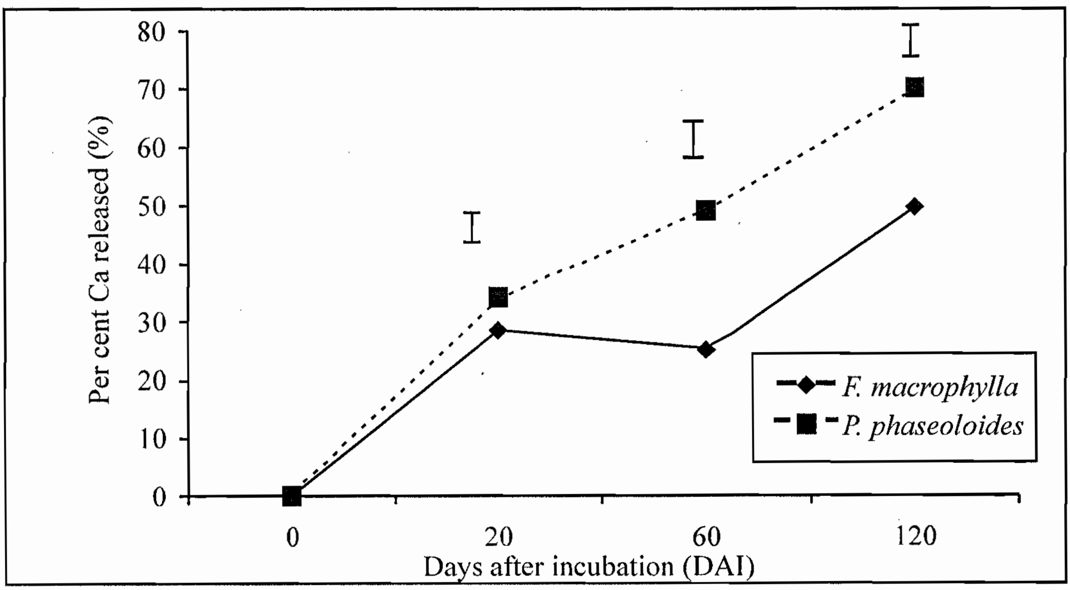

Figure 6. Calcium release patterns of leaf residues in Cameroon, 2004.

Magnesium

Magnesium releases were similar at 20 DAI but thereafter *P. phaseoloides* released significantly greater amount of Mg than *F. macrophylla* (Figure 7). There were no significant residue x village interactions. The slowest Mg release was from *F. macrophylla* (0.0036 day^{-1}) with a half-life of about 27.5 weeks (Table 5). The release of Mg from *F. macrophylla* was even slower than the release of Ca from the same leaf residue, contrary to that observed in *P. phaseoloides*. The release of Mg followed a pattern similar to the other nutrients in both villages.

Discussion

Mass loss rates of residue

The mass loss of *P. phaseoloides* and *F. macrophylla* leaf residue, clearly indicated that decomposition was faster in *P. phaseoloides* leaves. This corroborated the findings of Norgrove *et al.* (2000) that crop residues with greater nutrient contents decomposed faster. The high half-life values for *F. macrophylla* in this study, are comparable to earlier studies in south-eastern Nigeria (Henrot and Brussaard, 1997) and are indicative of a slow leaf decomposition. This slow decomposition rate could be related to

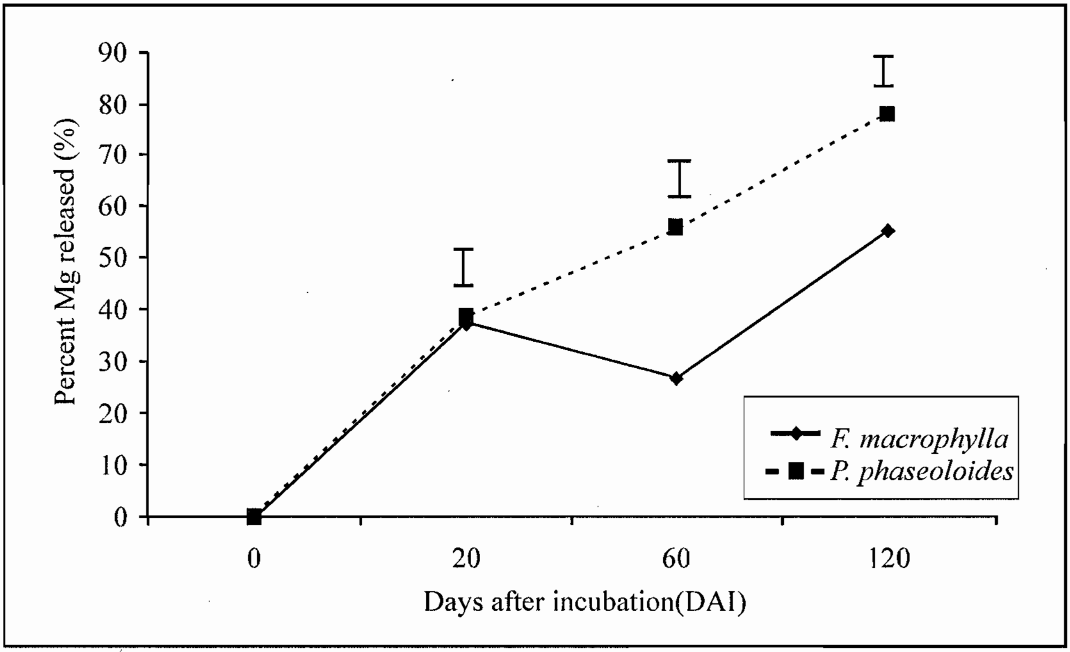

Figure 7. Magnesium release patterns of leaf residues in Cameroon, 2004.

the (Polyphenol + Lignin) / Nitrogen ratio, regarded as the most robust index (Mafongoya *et al.*, 1998). For *F. macrophylla* leaves the ratio is 8.2 (Zingore *et al.*, 2003) while it is 3.1 for *P. phaseoloides* (Tian *et al.*, 2001). The consequence of the slow decomposition of *F. macrophylla* is prolonged soil cover which could enhance infiltration of rainwater and subsequently increase moisture availability (Bhattacharyya and Rao, 1985) for the benefit of the associated crop. Leaf mass loss at Ngoumou, with a higher rainfall regime, was expected to be greater than at Nkometou because high monthly rainfall has been established as a site-specific factor that promotes decomposition of litter (Vanlauwe *et al.*, 1994; Steinberger and Ben-Ythak, 1990; Aerts, 1997; Henrot and Brussaard, 1997). However, the reversed trend was observed in this study such that mass loss was more at Nkometou than Ngoumou. This could be explained by the observed termite feeding activities on *F. macrophylla* in most of the *F. macrophylla* plots at Nkometou which most probably led to a rapid and excessive loss of leaf material, causing erroneously high estimates of 'decomposition' rates. Hauser *et al.* (2005) reported that *F. macrophylla* leaves attract termites. Moreover, the mesh size (2 mm x 2 mm) of the litterbags in this study was not too small to prevent the small bodied termites from accessing the *F. macrophylla* leaf material. Henrot and Brussaard (1997) indicated that the effect of macrofauna on mulch decomposition could be as large as 30 - 40%.

Nutrient release from residue

The faster N release from leaves of *P. phaseoloides* was expected since nutrient release rates are generally dependent upon mass loss rates. Such rapid N release might be vital as it could be in synchrony with crop demand during the early phases of crop development thereby boosting crop growth. The slow N release from *F. macrophylla* might be explained by the high (Polyphenol + Lignin) / Nitrogen ratio of *F. macrophylla*. Fox *et al.* (1990) reported that this index was highly correlated ® = 0.93) with N release in legumes. While rates of phosphorus release were similar for both leaf residues, K, Ca and Mg releases were greater for *P. phaseoloides* than *F. macrophylla*. Potassium release from the leaf residues was the fastest among all the nutrients, probably due to its high mobility and solubility (Marschner, 1995). Releases of Phosphorus from the leaf residues were generally faster than N releases, and could be beneficial to an associated crop for the rapid development of roots for anchorage and uptake of moisture and nutrients. The slowest releases were Ca and Mg which have important roles to play in crop nutrition but are not in high demand in the early stages of crop growth. On the other hand, Ca and Mg play crucial roles in the stability of surface soil aggregates (Salako and Hauser, 2001) which results in good soil tilth. The high nutrient release patterns of *P. phaseoloides* compared to *F. macrophylla* implied that short season crops, such as maize, might have a better nutrient synchrony with *P. phaseoloides* than *F. macrophylla*. Moreover, soil structure improvement with its attendant benefits of good water infiltration and aeration, might be achieved faster under *P. phaseoloides*.

Nkometou experienced greater releases of N, P, K, Ca and Mg but the rates of release were faster at Ngoumou. Whereas the greater rates of nutrient releases at Ngoumou could be related to its rainfall regime (Norgrove *et al.*, 2000), the greater amounts of nutrients released at Nkometou could be related to the observed feeding activities of termites on *F. macrophylla*.

Conclusion

The study clearly established that *P. phaseoloides* had the largest amounts and rates of nutrient releases and therefore could ensure greater nutrient availability to associated crops.

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